

Spatial structure and geometry of schools of sardine (*Sardinops sagax*) in relation to abundance, fishing effort, and catch in northern Chile

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We analysed the interrelationships of morphological, energetic, and relational descriptors of schools of sardines in the winter seasons of 1984–1990. A surface occupation index was used to measure the space covered by sardine. These descriptors were then related to catch, fishing effort, and catch per unit effort (cpue). We found that the greater the distance between the schools and the smaller the surface occupation index for schools, the smaller their size, biomass, and density. However, these descriptors were weakly related to the number of schools. The annual catch, fishing effort, and cpue were significantly and directly related to surface occupation index and inversely with the distance between schools. These fishery indices were weakly related to school area, school density, and school biomass. The change in the space occupied by sardine affected their catchability, as shown by the logarithmic relationship between the cpue and acoustic biomass. The lack of linearity can be corrected by taking into consideration the index of surface occupation of the stock so as to produce a corrected cpue (cpue*) value, which is directly proportional to stock biomass.

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Keywords: acoustic survey, catchability, cpue, density dependence, schools, small pelagics, spatial structure, surface occupation index.

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Introduction

In pelagic species, changes in stock abundance may not cause changes in catchability because of a density-dependence effect, which occurs when the school density spreads to remain constant despite a decrease in the number of schools or in the distribution area (Paloheimo and Dickie, 1964). This phenomenon can affect the abundance index used in the stock analysis, which is based on fisheries data, such as the catch per unit effort (cpue). When there are changes in factors such as the size and number of schools and clusters of schools, the density of the schools, the spatial distribution patterns, and the distribution area, the cpue may be biased because the relationship between cpue and abundance is not linear (Fréon *et al.*, 1993; Fréon and Misund, 1999). To achieve the linearity it is therefore necessary to include in the cpue factors associated with size of schools and/or distribution area. The spatial distribution of pelagic species and the size of schools can be deduced

from fisheries information (Yañez *et al.*, 1993) or obtained directly from periodic and systematic acoustic surveys.

The morphology of small pelagic schools and their organization in clusters of schools have been described for some pelagic stocks (Cram and Hampton, 1976; Petitgas and Lévênez, 1996; Mackinson *et al.*, 1997), and some effort has been made to determine the relationship between the spatial organization and the state of the stock (Petitgas *et al.*, 2001). However, there are a few studies in which acoustic surveys have been used to determine school morphology and variability, or that assess their effects on fishery indicators such as effort, catch, and cpue.

In this paper, we seek to determine a correction factor for bias in the cpue of sardine (*Sardinops sagax*) in northern Chile. This work analyses morphometric (length, height, area, and elongation), energetic (biomass and density), and relational (distance and coverage; Reid *et al.*, 2000) descriptors of the sardine during southern winters, as related to fishing effort, catch and cpue. The 1984–1990

period is analysed because the fishery peaked in 1985 and began to decline thereafter. Furthermore, the changes in the fishing yield were accompanied by modifications in the spatial distribution of the sardine, with an increase in dispersion of the aggregations and a weakening in the biomass seasonality (Castillo *et al.*, 1994).

Material and methods

Acoustic surveys and data

Between 1981 and 1995 seasonal acoustic surveys were carried out in northern Chile ($18^{\circ}20'S$ – $24^{\circ}00'S$) from the coast to 185 km offshore. In this paper, we use the winter biomass assessment results, which correspond to the main sardine spawning period (Castillo *et al.*, 1994). Between 1984 and 1990, specific measures of school characteristics were taken from echograms. The vessels used were “Itzumi” (1984), a 40.59-m stern trawler, and “Carlos Porter” (1985–1990), a 27-m trawler, using SIMRAD scientific systems, composed of EKS (“Itzumi”) and EKR (“Carlos Porter”) 38-kHz echosounders and QM-MK II analogue echo integrators, calibrated according to standard procedures (Foote *et al.*, 1987). The acoustic data were collected in 3.7-km sampling basic units (EDSU) and performed in parallel diurnal transects, separated by 55.6 km in 1984 and 46.3 km in all other years. A $-32.5 \text{ dB kg}^{-1} \text{ TS}_{\text{kg}}$ was applied to transform the echo integrator output into biomass. Species discrimination in the acoustic readings was done based on purse-seine fishing (“Carlos Porter”), performed by an auxiliary fishing ship, and midwater trawling (“Itzumi”).

Morphological school descriptors

School length and height were measured from echograms according to the procedure described by Johannesson and Losse (1977), modified by Misund (1993) and Scalabrin

and Massé (1993). Elongation (Elong) provides a measure of the school shape according to the following criteria: $\text{Elong} = 1$ for a circular school, $\text{Elong} > 1$ for an elliptical school with length $>$ height, and $\text{Elong} < 1$ for an elliptical school with height $>$ length (Scalabrin and Massé, 1993). The vertical cross section of the school was obtained by multiplying the height by the length.

Relational descriptors

The distance (Dist) between schools was determined using the number and size of EDSUs between nearest units containing sardine along each transect. An average was calculated for each survey. The surface occupation index (Co) is the relationship between the number of EDSUs containing sardine and the total number of EDSUs sampled during each survey.

Energetic descriptors

The acoustic density per school (ρ) was obtained according to Misund *et al.* (1992) and Johannesson and Losse (1977), with a TS_{kg} of -32.5 dB kg^{-1} . The school biomass (Bs) was calculated following the procedure of Misund *et al.* (1992), assuming that the volume of the school corresponds to a circular cylinder whose height is corrected by the length of the acoustic pulse (Olsen, 1969). The density per area (Dens) was estimated as the ratio of biomass to vertical cross area. Rich schools were defined as those of school biomass ≥ 200 tonnes. This value corresponded to the beginning of the long tail of school biomass histogram for all data of the seven surveys (Petitgas and L  v  nez, 1996). The variance of this type of school and the relative importance in the total variance were estimated.

The symmetry in the distributions of the descriptors was proven by means of the ratio among the skewness (g) and its standard error ($\text{s.e.}(g)$). The hypothesis of symmetry is rejected if the statistic is outside the range $[-2.2]$.

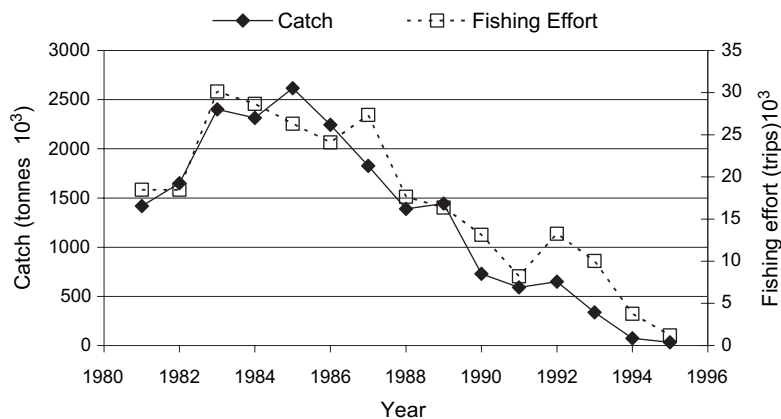


Figure 1. Time-series of sardine catch and fishing effort in the purse-seine fisheries of northern Chile.

Table 1. Statistics maxima, minima, and mean of sardine school descriptors, coefficient of variation (CV), skewness (g), and its standard error (s.e.(g)) by survey. The symmetry of distribution is rejected if the statistics $(g[s.e.(g)]^{-1})$ is outside the range $[-2.2]$.

Year	Number of schools	Statistic	Height (m)	Length (m)	School area (m ²)	School biomass (tonnes)	School density (tonnes km ⁻²)	Elong	Dist (km)	Co	
1984	203	Xmin	0.80	2.00	2.70	1.70	0.05	0.35	6.11	0.12	
		Xmax	35.80	184.30	1 264.90	3 322.12	3.21	67.40	20.37	0.34	
		\bar{x}	5.60	15.10	96.20	191.20	0.35	4.30	12.58	0.22	
		S(x)	4.70	16.20	155.50	402.90	0.13	6.40	4.60	0.06	
		$g[s.e.(g)]^{-1}$	12.40	35.90	5.10	30.00	3.62	33.50	0.37	0.44	
		CV(x)	0.84	1.07	1.62	2.11	0.37	1.49	0.37	0.27	
1985	208	Xmin	1.80	9.00	16.00	3.30	0.01	0.63	7.22	0.06	
		Xmax	31.80	180.00	3 480.80	3 933.90	2.33	20.70	26.48	0.30	
		\bar{x}	8.80	27.40	287.20	291.30	0.32	3.90	13.68	0.18	
		S(x)	5.40	21.20	397.40	461.10	0.10	3.00	6.14	0.08	
		$g[s.e.(g)]^{-1}$	5.60	19.90	26.80	21.60	4.49	14.00	1.44	0.03	
		CV(x)	0.61	0.77	1.38	1.58	0.31	0.77	0.45	0.44	
1986	228	Xmin	0.80	4.70	7.70	1.80	0.01	0.65	7.96	0.02	
		Xmax	23.80	107.80	814.10	846.40	0.61	72.80	45.37	0.32	
		\bar{x}	7.50	22.10	172.20	56.70	0.11	4.30	17.04	0.18	
		S(x)	4.30	14.20	156.70	87.10	0.03	6.70	9.63	0.10	
		$g[s.e.(g)]^{-1}$	7.50	11.90	12.00	30.40	3.44	43.20	3.77	-0.35	
		CV(x)	0.57	0.64	0.91	1.54	0.27	1.56	0.57	0.55	
1987	177	Xmin	0.80	5.00	3.90	1.00	0.01	0.80	8.15	0.02	
		Xmax	25.80	60.00	989.70	316.70	0.26	16.90	46.30	0.38	
		\bar{x}	6.20	18.50	125.20	27.30	0.06	3.70	23.54	0.16	
		S(x)	3.40	11.20	133.80	39.70	0.01	2.90	14.25	0.11	
		$g[s.e.(g)]^{-1}$	10.57	7.80	17.50	21.90	2.27	12.60	0.86	1.54	
		CV(x)	0.55	0.61	1.07	1.45	0.17	0.78	0.61	0.69	
1988	59	Xmin	1.80	9.00	16.00	1.70	0.00	0.90	8.89	0.02	
		Xmax	14.80	47.00	459.20	616.10	1.55	8.20	46.30	0.30	
		\bar{x}	7.30	20.70	157.50	97.00	0.20	3.30	23.65	0.12	
		S(x)	3.30	8.40	105.20	131.70	0.07	1.60	13.78	0.11	
		$g[s.e.(g)]^{-1}$	1.80	2.30	3.70	8.10	3.50	3.00	0.55	1.11	
		CV(x)	0.45	0.41	0.67	1.36	0.35	0.48	0.58	0.92	
1989	164	Xmin	0.80	2.20	1.70	2.50	0.01	0.50	7.04	0.02	
		Xmax	26.80	183.70	2 714.20	1 177.40	0.93	39.40	46.30	0.28	
		\bar{x}	8.60	22.40	234.40	162.90	0.26	3.20	16.08	0.17	
		S(x)	5.20	20.00	344.40	218.50	0.05	3.60	11.75	0.09	
		$g[s.e.(g)]^{-1}$	6.60	21.60	21.00	12.40	1.66	36.70	3.15	-0.18	
		CV(x)	0.60	0.89	1.47	1.34	0.19	1.13	0.73	0.53	
1990	88	Xmin	0.80	2.20	1.70	2.50	0.00	1.10	12.22	0.02	
		Xmax	19.80	349.00	2 015.50	905.90	0.64	62.70	46.30	0.36	
		\bar{x}	5.20	34.20	221.10	61.40	0.12	7.90	33.18	0.09	
		S(x)	4.00	48.30	363.00	118.80	0.03	10.60	15.48	0.12	
		$g[s.e.(g)]^{-1}$	5.80	15.50	11.70	18.70	2.59	15.00	-0.61	3.00	
		CV(x)	0.77	1.41	1.64	1.93	0.25	1.34	0.47	1.33	
Total	1 127	Xmin	0.80	2.00	1.70	1.00	0.00	0.40	6.11	0.02	
		Xmax	35.80	349.00	3 480.80	3 934.00	3.21	72.80	46.30	0.38	
		\bar{x}	7.20	22.70	184.50	137.50	0.23	4.20	18.63	0.17	
		S(x)	4.70	21.40	271.10	296.00	0.09	5.60	11.99	0.10	
		$g[s.e.(g)]^{-1}$								4.75	0.57
		CV(x)	0.65	0.94	1.47	2.15	0.39	1.33	0.64	0.59	

Table 2. Analysis of variance of school descriptors, logarithms transformed, for sardine.

Descriptor (log)	Source of variation	Sum of squares	d.f.	Mean squares	F	p
School height	Between years	10.44	6	1.740	24.69	0.0001
	Within years	80.32	1 140	0.071		
	Total	90.75	1 146			
School length	Between years	12.38	6	2.060	25.44	0.0001
	Within years	92.42	1 140	0.081		
	Total	104.80	1 146			
School area	Between years	39.53	6	6.590	32.13	0.0001
	Within years	233.74	1 140	0.210		
	Total	273.26	1 146			
School biomass	Between years	227.50	6	37.920	121.31	0.0001
	Within years	356.32	1 140	0.310		
	Total	583.82	1 146			
School density	Between years	175.58	6	29.260	192.63	0.0001
	Within years	173.18	1 140	0.150		
	Total	348.75	1 146			
Elongation	Between years	6.10	6	1.020	10.38	0.0001
	Within years	111.74	1 140	0.098		
	Total	117.84	1 146			

Fishery data

The catch and fishing effort data set used was collected from the purse-seine fisheries of the northern area of Chile. The unit of fishing effort was fishing trips, with captures standardized to the master boat (Böhm *et al.*, 1996).

Results

During the period 1981–1995, the annual catch of sardine decreased steadily, varying from 2.6 million tonnes in 1985 to 31 thousand tonnes in 1995 (Figure 1). The fishing effort showed four phases: a growth phase between 1981 and 1983; a stable phase between 1983 and 1987; a moderately declining phase between 1988 and 1991; and an unstable phase of reduction in 1992 and 1995 (Böhm *et al.*, 1996). The reduction in sardine fishing effort was attributed to a combination of two factors: the decreasing abundance of the species, and the replacement of the fleet target species. As of 1985, the fleet targeted anchovy (*Engraulis Fingens*), which had been virtually absent in this zone before this period (Castillo *et al.*, 1994; Böhm *et al.*, 1996).

All school descriptors show considerable interannual variability, and for most of them the distribution of observations was asymmetric in every survey (Table 1). The ANOVA confirmed that all descriptors, which were log-transformed, showed significant differences among years (Table 2).

Mean school height, length, and school size, measured through vertical cross area, fluctuated synchronously throughout the period, with minima in 1984 and 1987,

and a maxima in 1985 (Table 1). One exception to this behaviour was in 1990, when length increased and height decreased. In general, the schools had an elliptical shape, with a length four times greater than the height on average (Table 1), except in 1990 when the school assumed a disc shape, due to a doubling in the relative length of the school (Elong = 7.93). The number of schools remained almost the same from 1984 to 1986, decreasing only slightly after 1987, while the distance between schools increased and the surface occupation index for sardine diminished, varying inversely with the distance (Table 1).

The mean school density and school biomass values showed important differences between years, with a generally decreasing trend (Tables 1, 3). Only in 1988 and 1990 did school density depart from that trend. The distance between schools showed a significant inverse relationship with school biomass ($R^2 = 0.75$; $p < 0.05$) and school density ($R^2 = 0.72$; $p < 0.05$) (Table 3), suggesting that schools were smaller in dimension as distance increased. Both biomass and density were associated with the surface occupation index. The number of schools was weakly associated with abundance descriptors, being apparently independent of both abundance descriptors (Table 3). The “rich” schools had the greatest impact on biomass, contributing with more than 78% in 1984 and 1985 (Table 4). The lowest frequency of this type of school was associated with the lowest biomass in 1987.

The annual catch, fishing effort, and cpue had a significant relationship with the surface occupation index for sardine, with a positive slope (Table 3). These three fishery indicators were inversely related with distance ($p < 0.05$),

Table 3. Linear correlation between mean school descriptors, fishery indicators, relational school descriptors, and number of school (n) by year. School descriptors: school biomass (Bs) in tonnes; school density (Dens) in tonnes km⁻²; height (m); length (m); school vertical cross area (As) in m², and elongation (Elong). Fishery indicators: catch (C) in tonnes, fishing effort (E) in trips, cpue (tonnes trip⁻¹); cpue corrected (cpue*) in tonnes trip⁻¹. Relational school descriptors: distance (Dist) in km, and school surface occupation index (Co). The correlations with values equal or greater than R = 0.76 are significant (p < 0.05).

Year	C	E	cpue	cpue*	Bs	Elong	Height	Length	Dens	Dist	Co	As	n
Year	1.00												
C		-0.94											
E			0.89										
cpue				1.00									
cpue*					1.00								
Bs						1.00							
Elong							1.00						
Height								1.00					
Length									1.00				
Dens										1.00			
Dist											1.00		
Co												1.00	
As													1.00
N													

Table 4. Contribution to biomass and variance of schools that exceed the 200 level.

Year	School biomass ≥ 200 (%)	Contribution to mean biomass (%)	Contribution to variance (%)
1984	23.15	78.82	89.75
1985	35.09	85.41	83.62
1986	5.70	33.79	80.81
1987	1.69	15.55	56.42
1988	11.86	51.16	81.87
1989	23.17	68.96	80.23
1990	7.96	29.31	19.66

and weakly related with school area and school density (p > 0.05). The capture and cpue were directly correlated with school biomass.

With evidence that the spatial occupation of sardine is the factor related with cpue, the series of cpue data was extended to the period 1981–1995. In addition, a new surface occupation index, from the winter acoustic survey, was obtained, and the winter acoustic biomass was considered. The cpue was stable between 1981 and 1989, with some interannual variability, and a decreasing trend starting in 1990 significantly fitted to a quadratic polynomial equation ($cpue = -2549867.47 + 2569.8672 \text{ Year} - 0.6474838 \text{ Year}^2$; $R^2 = 0.85$; $p < 0.005$; $n = 15$) (Figure 2). The winter acoustic biomass of the 1981–1995 period, described by an exponential equation ($Bo = 3.40 \times 10^{(2.16 - 0.106 \text{ Year})}$; $R^2 = 0.71$; $p < 0.05$; $n = 15$), fluctuated between 5 and 5.3 million tonnes in 1981–1982 down to 0.8 million tonnes in 1992 (Figure 2). This new surface occupation index was then multiplied by the annual cpue to obtain a corrected cpue (cpue*). In this way the cpue* time-series shows a significant fit to an exponential equation ($cpue^* = 2.46 \times 10^{(2.30 - 0.115 \text{ Year})}$; $R^2 = 0.86$; $p < 0.05$; $n = 15$) (Figure 3), which is similar to the fitted equation for the acoustic winter biomass, and different from the equation that was obtained from the biomass and the uncorrected cpue. The relationship between the cpue and the winter biomass is fitted to a non-linear equation ($cpue = 32.01 \log(Bo) - 123.65$; $R^2 = 0.52$; $p < 0.05$; $n = 15$), while the cpue* is well represented by a linear function to biomass ($cpue^* = 6.35 \times 10^{-6} Bo + 0.64$; $R^2 = 0.94$; $p < 0.05$; $n = 15$), thereby achieving proportionality between the two indexes (Figure 3). The ratio between cpue* and biomass represents the catchability.

Discussion

It is evident that the interannual reduction in total biomass was caused by the decrease in frequency of rich schools. There is also a weak relationship between the number of schools and their biomass. Marchal and Petitgas (1993) found similar results in Venezuela, and Petitgas *et al.*

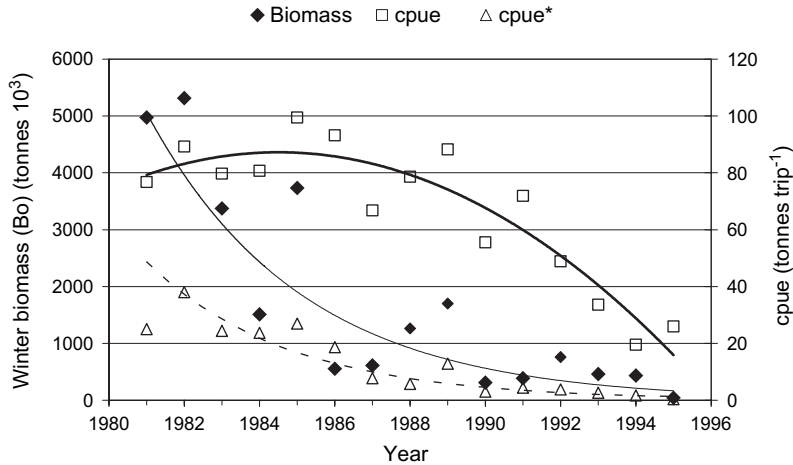


Figure 2. Time-series of winter acoustics biomass (Bo; thin continuous line, solid diamonds), uncorrected cpue (thick continuous line, open squares), and corrected cpue by the surface occupation index (cpue*; dashed line, open triangles).

(2001), too, had similar findings in the coastal areas of Europe.

Factors such as school density and school biomass had low significance with respect to capture and fishing effort, which in turn were associated with spatial occupation of the region by sardine, such as the surface occupation index and distance. On the other hand, when the surface occupation index was high and the population was distributed over a larger area, the fishing effort was lower and the catches were larger. This density-dependence is common in fisheries for small pelagics, especially in periods of stock collapse, causing catchability to increase when the stock biomass decreases. Paloheimo and Dickie (1964) and Mackinson *et al.* (1997) stated that, in periods of stock

collapse, the change in catchability coefficient is due to the greater effectiveness of the fishing fleet and modifications in the aggregation behaviour of the fish. The density-dependence in catchability (q) has been observed in several pelagic fisheries, showing an inverse power relationship with regard to the biomass (B) ($q = aB^{-b}$). In this study, the cpue does not adequately represent abundance because of a bias in catchability caused by the spatial distribution of sardine. Once the surface occupation index, which represents the spatial distribution pattern of the stock, is applied to the cpue, the relationship between biomass and cpue becomes a linear one. In this way, the catchability becomes constant, being adjusted to the Schaefer model ($q = cpue B^{-1}$).

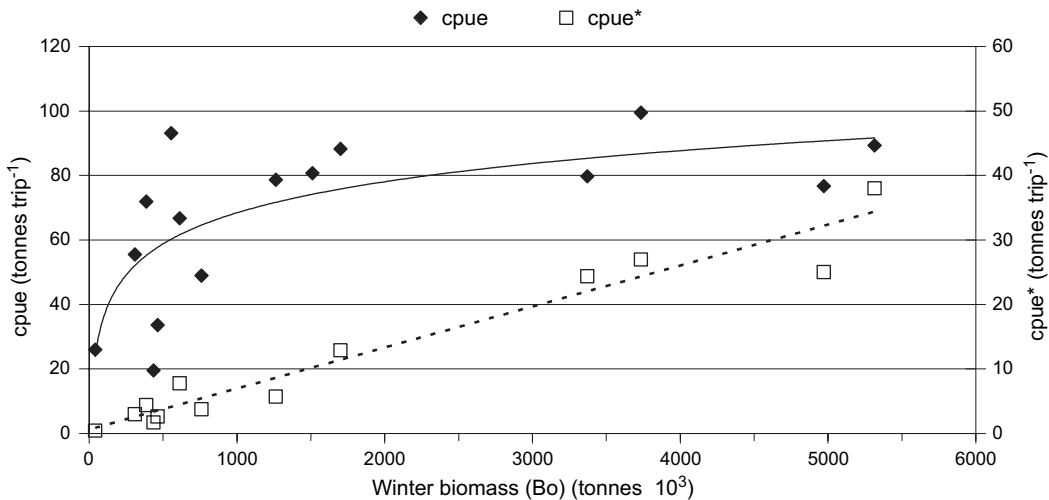


Figure 3. Relationship between winter acoustics biomass (Bo), with uncorrected cpue (continuous line, closed diamonds) and corrected cpue by the surface occupation index (cpue*; dashed line, open squares).

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References

- Böhm, G., Barbieri, M., Yañez, E., González, A., Canales, C., and Catasti, V. 1996. Análisis de la captura y del esfuerzo de pesca de las unidades de pesquería de sardina española y anchoveta de la zona norte. Technical Report for the Fisheries Research Fund. Instituto de Fomento Pesquero, Chile. 111 pp.
- Castillo, J., Blanco, J., Braun, M., Reyes, H., and Robotham, H. 1994. Evaluación directa del stock de sardina española, anchoveta y jurel (Regiones I a IV). Technical Report for the Fisheries Research Fund. Instituto de Fomento Pesquero, Chile. 108 pp.
- Cram, D., and Hampton, I. 1976. A proposed aerial/acoustic strategy for pelagic fish stock assessment. *Journal du Conseil International pour l'Exploration de la Mer*, 37: 91–97.
- Footo, K., Knudsen, H., Vestnes, G., MacLennan, D., and Simmonds, J. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. *ICES Cooperative Research Report*, 144. 57 pp.
- Fréon, P., Gerlotto, F., and Misund, O. 1993. Consequences of fish behaviour for stock assessment. *ICES Marine Science Symposia*, 196: 190–195.
- Fréon, P., and Misund, O. 1999. Dynamics of Pelagic Fish Distribution and Behaviour: Effects on Fisheries and Stock Assessment. Fishing News Books, Blackwell Science, Oxford. 348 pp.
- Johannesson, K., and Losse, G. 1977. Methodology of acoustic estimations of fish abundance in some UNDP/FAO resource survey projects. *Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer*, 170: 296–318.
- Mackinson, S., Sumaila, U. R., and Pitcher, T. 1997. Bioeconomics and catchability: fish and fishers behaviour during stock collapse. *Fisheries Research*, 31: 11–17.
- Marchal, E., and Petitgas, P. 1993. Precision of acoustics fish abundance estimates: separating the number of schools from the biomass in the schools. *Aquatic Living Resources*, 6: 211–219.
- Misund, O., Aglen, A., Beltestad, A., and Dalen, J. 1992. Relationships between the geometric dimensions and biomass of schools. *ICES Journal of Marine Science*, 49: 305–315.
- Misund, O. 1993. Dynamics of moving masses: variability in packing density, shape, and size among herring, sprat, and saithe schools. *ICES Journal of Marine Science*, 50: 145–160.
- Olsen, S., 1969. A note on estimating school size from echo traces. Technical Report, ICES/FAO Acoustic, Training Course. Svolvær, Norway, 2–15 March 1969. *FAO Fisheries Report*, 78: 37–40.
- Paloheimo, J., and Dickie, L. 1964. Abundance and fishing success. *Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer*, 155: 152–163.
- Petitgas, P., and Lévêze, J. 1996. Spatial organization of pelagic fish: echogram structure, spatio-temporal condition, and biomass in Senegalese waters. *ICES Journal of Marine Science*, 53: 147–153.
- Petitgas, P., Reid, D., Carrera, P., Iglesias, M., Georgakarakos, S., Liorzou, B., and Massé, J. 2001. On the relation between schools, clusters of schools, and abundance in pelagic fish stocks. *ICES Journal of Marine Science*, 58: 1150–1160.
- Reid, D., Scalabrin, C., Petitgas, P., Massé, J., Auckland, R., Carrera, P., and Georgakarakos, S. 2000. Standard protocols for the analysis of school based data from echo sounder surveys. *Fisheries Research*, 47: 125–136.
- Scalabrin, C., and Massé, J. 1993. Acoustic detection of the spatial and temporal distribution of fish shoals in the Bay of Biscay. *Aquatic Living Resources*, 6: 269–283.
- Yañez, E., Canales, C., Barbieri, M., González, A., and Catasti, V. 1993. Estandarización del esfuerzo de pesca y distribución espacial e interanual de la c.p.u.e. de anchoveta y de sardina en la zona norte de Chile entre 1987–1992. *Investigaciones Marinas, Valparaiso*, 21: 111–132.